

TETRASTICHUS BREVISTIGMA GAHAN,¹ A PUPAL PARASITE OF THE ELM LEAF BEETLE

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INTRODUCTION

Tetrastichus brevistigma Gahan, an internal, gregarious parasite which attacks the pupae of the elm leaf beetle, *Galerucella xanthomelaena* (Schr.), was first discovered on August 8, 1932, by C. L. Griswold, of the Melrose Highlands, Mass., laboratory, who found thousands of them issuing from pupae of the elm leaf beetle collected at Danvers, Mass., late in July. In view of the fact that this was a new parasite of such promising economic importance, it was thought advisable to make a detailed study of its distribution, life history, habits, and effectiveness.

DISTRIBUTION

Britton³ stated in 1932 that the elm leaf beetle was a native of Europe and first injured elm trees in this country in the vicinity of Baltimore, Md., in 1838–39. Since that time it has spread throughout the Eastern States and as far west as Indiana and Kentucky, and is also present in California, Oregon, and Washington.

In 1932 and 1933 elm leaf beetle pupae from several of the Northeastern States were isolated in small vials and held for emergence. Pupae parasitized by *Tetrastichus brevistigma* were found in most of the collections, and these indicated a wide distribution and in many cases a high percentage of parasitization. As far as known at present *T. brevistigma* is the only hymenopterous parasite of this stage of the

¹ Order Hymenoptera, family Eulophidae.
² This study was conducted at the Melrose Highlands laboratory of the Bureau of Entomology and Plant Quarantine from 1932 to 1935, inclusive. The writer is indebted to C. W. Collins, in charge of the laboratory previous to 1935, and to R. C. Brown, in charge during 1935, for making these investigations possible; and to P. B. Dowden for helpful advice.
³ BRITTON, W. E. THE ELM LEAF BEETLE OUTBREAK. Conn. Agr. Expt. Sta. Cir. 84, pp. 29–34, illus. 1932.

beetle. It would seem to be native to the United States, as no records of its attacking elm leaf beetle pupae have been made in other countries.

This parasite has been reared from collections of host material from New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, and Ohio, and in Washington, D. C. In fact, it has been reared in every section in the northeastern part of the United States from which the writer has been able to obtain sample collections of from 200 to 500 beetle pupae made during the late part of the season. There were a few collections from Virginia but these did not show parasitization. In Massachusetts, where most of the investigational studies were made, *Tetrastichus* was present in every elm leaf beetle infestation observed.

There are no records of parasites attacking the elm leaf beetle pupae in the Western States. In 1933 H. S. Smith made several collections of beetle pupae at different points in California and held them for emergence, but he stated that no parasites were present. In 1934 two shipments of *Tetrastichus brevistigma* were sent to him for colonization in California. One shipment consisted of about 15,000 adults and the other of 3,000 parasitized host pupae. From these lots 4 colonies totalling about 18,600 individuals were colonized at Orangevale, Fresno, Visalia, and Port Costa. Later collections of host pupae at Port Costa on September 20, 1934, revealed that the parasite had passed through one generation in the field at that point.

LIFE HISTORY AND HABITS

HIBERNATION

Tetrastichus brevistigma passes the winter as a full-grown larva in the pupal skin of its host. The percentage of the total number of larvae of a generation that will hibernate increases from generation to generation, as the season advances, and practically all the full-grown larvae of the last generation hibernate. Out of 1,838 parasitized pupae collected in 1934, adults issued from 1,012, or 55.1 percent, while the parasite larvae hibernated in the remaining 826, or 44.9 percent. In 1935 a total of 1,032 parasitized pupae were collected, and adult parasites issued from 499 pupae, or 48.4 percent, while parasite larvae hibernated in the remaining 533, or 51.6 percent. The increased percentage of overwintering lots was probably due to the delayed season of 1935.

The dead beetle pupae, in which the hibernating parasite larvae pass the winter, are found on the trunks and in the grass and debris surrounding the bases of the elm trees. Those on the trunks are usually concealed in crevices or behind bits of bark where some protection from birds and rodents is afforded. The parasite larvae hibernating within beetle pupae on the bark as well as in the grass at the base of the trees survived the unusually low temperatures of the winters of 1933-34 and 1934-35. There is always some loss due to the natural agencies of wind and water. Many exposed pupae were on the bare ground around the base of the trees, and these were practically all carried away by such agencies during the winter.

The winter mortality of the parasite larvae is very low. In the spring of 1934 collections were made from the tree trunks and ground.

There was a mortality of 5 percent in the collections from the trunks and of 7 percent in those from the ground. In the case of the spring collections made in 1935 there was a larval mortality of 8 percent in material taken from the trees and of 10 percent in that from the ground. These collections consisted of 100 parasitized beetle pupae each year. In 1934 several thousand parasite larvae were held in a wooden box in an outside insectary. A sample of 1,000 larvae from this lot showed a mortality of only 3 percent.

EMERGENCE

The time required for developing from the hibernating larvae to the adult parasites depends to a great extent on the season. In 1934 the peak of emergence for hibernating material held in an unheated insectary occurred between June 12 and 20. In 1935, emergence for hibernating material held under the same conditions as in 1934 was about 4 days later, the peak of emergence being from June 16 to 22. In both cases emergence was about 10 days earlier than that observed in the field. The parasites are in the field early enough to attack the first pupating larvae of the beetle, and continue to emerge from overwintering host pupae until about the middle of July.

Tetrastichus brevistigma issues, as a rule, from the host pupa. Occasionally, however, this parasite issued during the summer from hosts that had transformed to the adult stage. In 1934 four parasites issued from one adult beetle, and in 1935 four beetles produced from one to three adult parasites each. Emergence holes were in all cases in the ventral part of the thorax. The beetles that developed from the parasitized pupae lived only a few days, and the parasites issued from the dead hosts.

NUMBER OF GENERATIONS

Adults developing from overwintering larvae of the parasite were considered as belonging to the first generation. In addition to these, two complete generations and a partial third were reared in the laboratory, where the first emerging adults were used to start the subsequent generations. During the summer a complete generation of the parasite may take from 19 to 34 days. Adults of the first generation consisting of those developing from overwintering larvae started issuing June 12 in 1934. Adults of the second generation reared in the laboratory started emerging July 20, those of the third August 9, and those of the fourth, September 10. There were host pupae in the field for a short time after the third-generation adults started emerging, and practically all of the progeny of the third-generation adults overwintered as larvae. Nevertheless a few fourth-generation adults appeared about September 10. In the area where the beetle has only one generation annually these would be doomed to die without ovipositing, for at that late date all host pupae had disappeared.

In the field somewhat different conditions prevailed in that year. There was an overwintering generation which was complete and three summer generations that were only partial. The different generations were not clearly defined and there was considerable overlapping all through the season. There were, however, overwintering larvae from July 11 collections and from each collection throughout the remainder of the season.

Figure 1 shows the overlapping of the generations in the field and the time when adults of each are present. It also shows the period during which pupae of the elm leaf beetle are available for attack in regions where only one generation of this beetle occurs. According to Start, Stone, and Fernald ⁴ there is annually one complete and occasionally a partial second generation of the elm leaf beetle in Massachusetts.

MATING

Tetrastichus brevistigma mates fairly readily in confinement, apparently requiring no special conditions. Mating may take place immediately after emergence or it may be delayed several days. The whole

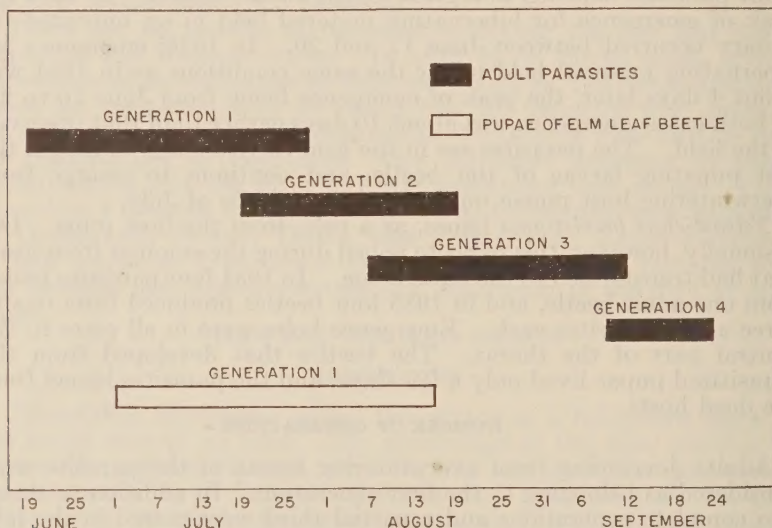


FIGURE 1.—Seasonal interrelationships of *Tetrastichus brevistigma* and its host in the area where only one generation of the elm leaf beetle occurs.

process of mating may require an hour or more. Actual union, however, in all cases observed, lasted only a few seconds, the shortest period being 5 seconds and the longest 57, with an average of 30 seconds for the eight cases observed.

OVIPOSITION

Tetrastichus brevistigma oviposits freely in pupae or prepupae of the elm leaf beetle. Females begin ovipositing within a few minutes after emergence, whether mating has taken place or not. The act of oviposition requires from 5 to 30 minutes. From one to eight eggs are deposited at each insertion of the ovipositor. The parasites may attack the same host pupa more than once.

FECUNDITY

In 1934 and 1935 two series of experiments were conducted to determine the reproductive capacity of the females. In each of these

⁴ START, E. A., STONE, G. E., and FERNALD, H. T. SHADE TREES. Mass. Agr. Expt. Sta. Bull. 125, 64 pp., illus. 1908.

experiments 20 females were isolated in 1- by 4-inch vials. The parasites were fed on a honey-and-water solution and were well supplied with fresh pupae each day. The exposed pupae were removed from the vials daily and dissected, the number of eggs from each being recorded. The parasites did not live very well under the close confinement, and the results of these experiments were somewhat disappointing. Five of the forty females died before ovipositing, and the remaining 35 produced from a minimum of 5 eggs to a maximum of 103. The average number of eggs for the whole lot was 40 per female.

Another experiment with 10 females in a glass vial 2 by 8 inches was conducted in a similar manner. From this group 560 eggs were obtained, or an average of 56 eggs each for the 10 parasites. The parasites lived longer and appeared more active than those confined in the smaller vials.

LONGEVITY

Five hundred adults were placed in a wooden box with a glass cover and kept in a dark room where the temperature ranged from 68° to 70° F. They were fed a mixture of honey and water in the proportion of about 1 to 5. The dead were removed at weekly intervals. Mortality was 15 percent the first week, 16 the second, 19 the third, 40 the fourth, and 9.6 percent the fifth. There were still two living adults at the end of the fifth week.

When kept at temperatures of 85° to 90° F., adults lived only 3 weeks, and the mortality was more than 50 percent at the end of the first week.

COMPETITION

In view of the high percentages of parasitization attained during the latter part of the season, it is inevitable that a heavy loss should occur through superparasitization. No apparent discrimination is exercised by the female in choice of hosts, and as many as 100 eggs and first-instar larvae have been found within a single host pupa. The number of mature larvae ranges from 1 to as many as 37 per host pupa, with an average of about 12 each. As in the case of *Tetrastichus giffardianus* Silv., reported by Pemberton and Willard,⁵ there is no apparent cannibalism, but this species differs from *T. giffardianus* in that there is a high mortality of the larvae in the early instars in place of a great number of dwarfed individuals. No reason for the death of the larvae, other than lack of food, can be given, but from observations to date it is doubtful whether many more than 37 larvae can reach maturity in a single host.

SEX RATIO AND PARTHENOGENESIS

Males occur rather rarely in this species and, although 833 adults were examined in 1932 and 1933, not a single male was found. Periodic examinations of material collected in the field and reared in the laboratory were continued in 1934, and in this year a few males were found issuing about the middle of the season. They became slightly more numerous during the latter part of the season, when 30 were found in a sample of 1,000 adults.

Reproduction work in the laboratory involving several hundred individuals failed to produce a single male. In these experiments unmated

⁵ PEMBERTON, C. E., and WILLARD, H. F. A CONTRIBUTION TO THE BIOLOGY OF FRUIT-FLY PARASITES IN HAWAII. Jour. Agr. Research 15: 419-466, illus. 1918.

females only were used. Nothing is known concerning the progeny of mated females. If only mated females produce males, however, there are indications that even among their progeny the percentage of males is low, for where 10 to 25 adult parasites emerged from isolated hosts there was seldom more than 1 male, although occasionally 2 or 3 emerged.

DESCRIPTIONS

THE ADULT

Tetrastichus brevistigma (fig. 2) has recently been described by Gahan ⁶ from material reared during the course of this study, and this description need not be repeated here.

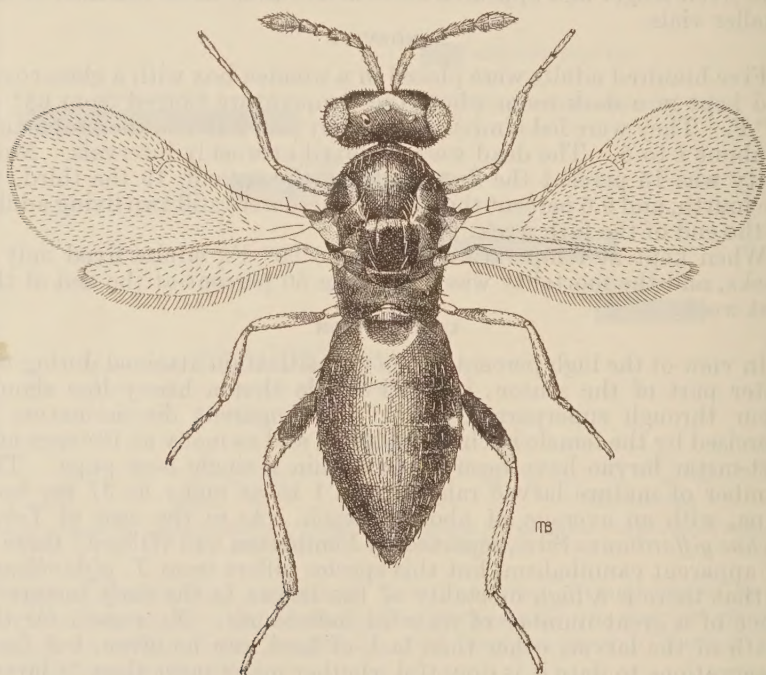


FIGURE 2.—Adult female of *Tetrastichus brevistigma*, $\times 65$. (Drawing by Mary F. Benson.)

THE EGG

The egg (fig. 3, *C*) of *Tetrastichus brevistigma* measures 0.288 mm in length and 0.076 mm at its greatest width near the cephalic end. It is circular in cross section and slightly curved lengthwise, opaque white, and has a smooth surface.

The time spent in the egg stage is influenced by the temperature. In July and August when the temperature ranged from 70° to 95° F. the duration of this stage was from 2 to 5 days.

⁶ GAHAN, A. B. *TETRASTICHUS BREVISTIGMA*, NEW SPECIES (HYMENOPTERA; EULOPHIDAE). Ent. Soc. Wash. Proc. 38: 76-77. 1936.

THE LARVAL INSTARS

Only brief general descriptions of the larval instars will be given. The first-instar larva (fig. 3, *B*) averages 0.51 mm in length and 0.20 mm in cross section. The body, exclusive of the head, has 13 segments. When newly hatched, it is widest at the first abdominal segment and from here it tapers gradually to the caudal end. It is cylindrical, almost transparent when first hatched, the central portion becoming dark as the larva ingests food. Each segment except the first has a single row of short hairs or spines which encircle the body except on the ventral portion.

The relatively small, slightly sclerotized head is almost transparent and bears a pair of small, slightly arched, almost transparent mandibles (fig. 3, *D*) which measure 0.07 mm in length.

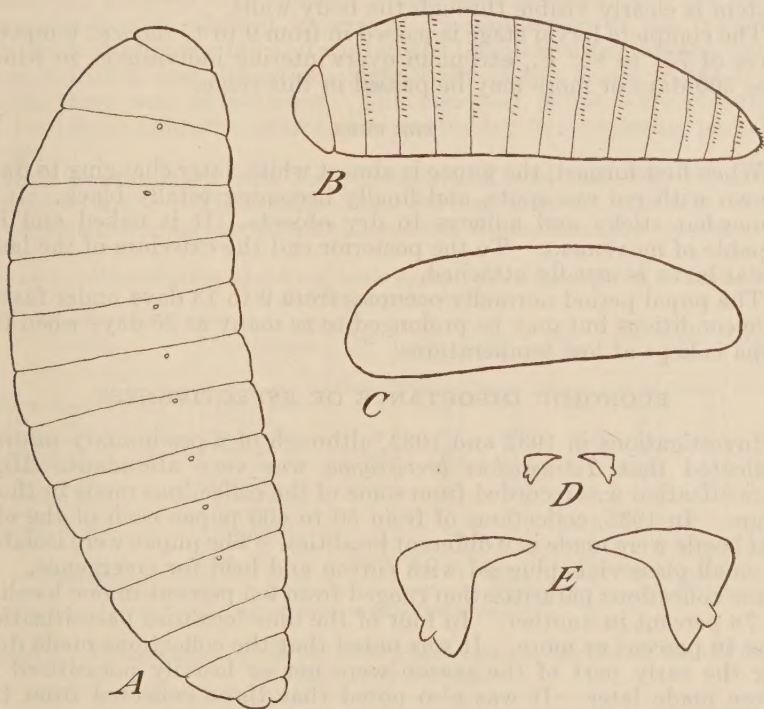


FIGURE 3.—*Tetrastichus brevistigma*: A, Mature larva, $\times 33$; B, first-instar larva, $\times 125$; C, egg, $\times 190$; D, first-instar mandibles, $\times 71$; E, mandibles of mature larva, $\times 58$.

The number of instars has not been determined, but after the first molt the larvae take on the general appearance and characteristics of the full-grown larvae of this group. They differ from the first-instar larvae in that there is an increase in size and the head and mandibles become more heavily sclerotized. The rows of spines partly encircling each body segment are lost, and the larva appears more or less wrinkled.

The full-grown larva differs from that of *Tetrastichus xanthomelae-nae* Rond., which is figured by Parker,⁷ in the number and location of the spiracular openings. An outline drawing (fig. 3, *A*) shows the general shape. When extended in water, the length averages 2.79 mm and the width 1.07 mm. It has a clearly defined head and 13 body segments and is still almost transparent except that the contents of the midintestine are dark and show plainly through the body walls.

The surface of the body is free from spines or hairs, and is smooth when distended, but as it occurs naturally it is wrinkled and any dry object clings to it. The mandibles (fig. 3, *E*) measure 0.345 mm in length and are fairly heavily chitinated. The location of the spiracular openings differs from that of chalcid larvae in general. There are eight openings, and these occur on the second and third thoracic and on the second to seventh abdominal segments. The whole tracheal system is clearly visible through the body walls.

The complete larval stage is passed in from 9 to 15 days at temperatures of 75° to 85° F., except in overwintering individuals, in which case 300 days or more may be passed in this stage.

THE PUPA

When first formed, the pupae is almost white, later changing to dark brown with red eye spots, and finally becoming totally black. It is somewhat sticky and adheres to dry objects. It is naked and incapable of movement. To the posterior end the exuvium of the last-instar larva is usually attached.

The pupal period normally occupies from 9 to 13 days under favorable conditions but may be prolonged to as many as 25 days when the pupa is kept at low temperatures.

ECONOMIC IMPORTANCE OR EFFECTIVENESS

Investigations in 1932 and 1933, although of a preliminary nature, indicated that *Tetrastichus brevistigma* was very abundant. High parasitization was recorded from some of the collections made in those years. In 1933, collections of from 50 to 400 pupae each of the elm leaf beetle were made in 9 different localities. The pupae were isolated in small glass vials plugged with cotton and held for emergence. In these collections parasitization ranged from 0.5 percent in one locality to 78 percent in another. In four of the nine localities parasitization was 46 percent or more. It was noted that the collections made during the early part of the season were not so heavily parasitized as those made later. It was also noted that those collected from the tree trunks were more heavily parasitized than those from the ground. In view of these observations it seemed advisable to make a more systematic study of this parasite and its host, and plans for this study in 1934 were drawn up accordingly.

Early in the spring of 1934 five localities were selected for observation and study of the elm leaf beetle and its parasite *Tetrastichus brevistigma*. In these plots periodic collections of beetle pupae for rearing and determination of parasitization and for observations on the abundance of the elm leaf beetle were made throughout the seasons in 1934 and 1935. The observation points were in Woburn, North

⁷ PARKER, H. L. RECHERCHES SUR LES FORMES POST-EMBRYONNAIRES DES CHALCIDIENS. ANN. Soc. Ent. France 93: [261]-379, illus. 1924.

Attleboro, Middleboro, and Weymouth, Mass., and Hampton, N. H. At each of these points weekly collections of 200 elm leaf beetle pupae, 100 from the tree and 100 from the ground, were made.

The selection of a fair sample of host pupae was rather difficult. Freshly formed beetle pupae were less likely to be parasitized than older pupae. On the other hand, parasitized pupae remained in the field after beetles had emerged from those that were not parasitized. Further investigations, however, showed that within 5 to 7 days after being attacked the parasitized beetle pupae could be recognized by their coloration. In order to obtain a fair sample, therefore, the freshly formed pupae and those showing signs of parasitization were avoided, the sample consisting then of pupae approximately 2 to 5 days old.

The collections were taken to the laboratory and isolated in small glass vials plugged with cotton. These were set aside and the parasites and beetles allowed to emerge. Examination of the material was made during the fall and winter, the issuance of beetles and parasites recorded, and dissections were made of the beetle pupae from which there was no issuance. The dissected pupae were classified as dead from unknown causes or as containing overwintering parasite larvae.

Data accumulated from the collections of 1934 and 1935 are given in tables 1 and 2. These tables show the fluctuations in the percentage of parasitization in the different localities throughout the season.

TABLE 1.—*Parasitization of elm leaf beetle pupae, collected at different dates in 1934, by Tetrastichus brevistigma*

Locality	Environment	July 3-6	July 11-13	July 18-20	July 26-27	Aug. 2-3	Aug. 9-10	Aug. 16
		<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Woburn, Mass.	Tree trunk	2	18	6	50	38	70	80
Do.	Ground		0	4	8	22	38	73
Middleboro, Mass.	Tree trunk	10	48	50	62	75	65	
Do.	Ground		5	15	16	71	68	
North Attleboro, Mass.	Tree trunk	14	44	64	83	100	69	
Do.	Ground		7	23	55	77	31	
Weymouth, Mass.	Tree trunk	10	23	33	190			
Do.	Ground		0	23				
Hampton, N. H.	Tree trunk		0	10	16			
Do.	Ground			5				
Average		1.4	16.1	23.3	52.2	63.8	56.8	76.5

¹ Collections of 200 pupae; all other collections contained 100 pupae each.

TABLE 2.—*Parasitization of elm leaf beetle pupae, collected¹ at different dates in 1935, by Tetrastichus brevistigma*

Locality	Environment	July 16- 17	July 23- 25	July 30- Aug. 2	Aug. 6-8	Aug. 14- 15
		<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Woburn, Mass.	Tree trunk	7	0	9	37	83
Do.	Ground	2	3	7	9	42
Middleboro, Mass.	Tree trunk	33	10	10	69	
Do.	Ground	9	0	0	11	
North Attleboro, Mass.	Tree trunk	30	1	9	66	
Do.	Ground	10	0	19	19	19
Weymouth, Mass.	Tree trunk	34	59	40	15	63
Do.	Ground	41	19	17	20	46
Hampton, N. H.	Tree trunk			49	22	56
Do.	Ground			16	12	20
Average		20.7	11.5	17.6	28.0	47.0

¹ 100 pupae in each collection.

Analysis and comparison of the data in the two tables show some interesting results and correlations. In most localities a decided increase in parasitization occurred from about the third to fourth week after beetle pupation began in the field. In both 1934 and 1935 the highest percentage of parasitization was evident during the latter part of the season.

In 1934 the life history of the parasite synchronized very well with that of the host. The parasitization increasing most rapidly at the time when host pupae were most abundant in the field. According to Britton and Friend⁸ the elm leaf beetle pupation is at its peak about July 15 in Connecticut. The peak of beetle pupation in Massachusetts was about July 18 in 1934. In 1935 the parasites evidently emerged too early, the peak of beetle pupation occurring when a high percentage of parasitization could not take place.

In practically all instances the parasitization of beetle pupae collected from the tree trunks was greater than that of those collected from the ground. This is to be expected, as those on the tree trunks, on the average, are more exposed to parasite attack than those on the ground around the base of the trees. In heavy beetle infestations a higher percentage of the beetle larvae migrate to the ground, where they crawl under any available debris. Masses of pupae 2 to 3 inches deep are not uncommon. In these thick masses of pupae only the upper layers of the host are exposed to parasite attack for at least a greater part of the time that the pupae are in the field.

The averages of the results from all localities show an increase in parasitization in each of the early weeks of the season of 1934. The greatest increase occurred in the fourth week, owing to the appearance of the second-generation adults, after which the parasitization was much higher. The results obtained in 1935 differ in that the first collections gave a rather high parasitization with a decided decrease the second week and no marked increase until the fourth week. The difference in the results for the two seasons can be explained only by the differences in the seasons. Owing to a delayed spring, beetle pupation was retarded about 10 days in 1935 while parasite emergence, in the laboratory at least, was retarded only about 4 days. Apparently many of the overwintering parasite larvae had developed to adults before beetle pupae were available and did not live long enough to attain as pronounced an overlapping of the first and second generations as occurred in 1934.

It is doubtful whether *Tetrastichus brevistigma* can control the elm leaf beetle when the beetle occurs in outbreak proportions and when other conditions are favorable for its development; but during this time the parasite is also building up in population to a high numerical level, and as soon as the host's upward swing is checked by adverse climatic conditions or other factors, the full force of the parasite attack would hasten the subjugation of the beetle. After the beetle was under control it would be reasonable to predict that the parasite would play an important role in increasing the interval between outbreaks. In regions farther south where the beetle has two complete generations a year the parasite may be more effective in reducing

⁸ BRITTON, W. E., and FRIEND, R. B. INSECT PESTS OF ELMS IN CONNECTICUT. Conn. Agr. Expt. Sta. Bull. 369, pp. 265-307, illus. 1935.

the numbers of its host than in regions where there is only one complete generation and an occasional partial second.

Spraying of foliage for the control of the elm leaf beetle appears to have little effect on the efficiency of the parasite, but where the soil and lawns are treated many of the parasites are undoubtedly killed.

SUMMARY

Tetrastichus brevistigma Gahan is an important internal parasite of the elm leaf beetle pupae and is well distributed throughout the northeastern part of the United States where the elm leaf beetle occurs.

The parasites overwinter as full grown larvae in the dead pupae of the host and emerge early enough in the spring to attack the first elm leaf beetle pupae that are formed. The parasite passes through three to four partial generations a year, the second-generation adults emerging about the time that beetle pupation is at its peak.

Tetrastichus brevistigma produces females parthenogenetically, and males are very rare.

About July 15, when the host population is at its peak, parasitization begins to increase rapidly. This is due to the appearance in the field of the second generation of *Tetrastichus*. Parasitization as high as 50 to 80 percent is quite common during the latter part of the season.

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